The Food of the Aholehole, *Kuhlia sandvicensis* (Steindachner), in Hawaiian Waters[1]

ALBERT L. TESTER and SHIRLEY M. TREFZ[2]

THE AHOLEHOLE, also known as the mountain bass, is an inshore fish which occurs in salt, brackish, and fresh waters throughout the Hawaiian Island chain. The young are fairly abundant along rocky shores, in tide pools, and within the mouths of streams which are connected to the sea. Juveniles are frequently encountered under wharves, in larger tide pools, and in brackish or fresh-water ponds, and streams. Adults are found in the caverns of wave-swept coral reefs, in the pounding surf at the base of cliffs, in sunken barges and other underwater obstructions, and, occasionally, as schools in more open water.

A study of the food of the aholehole was undertaken in connection with a general investigation of the life history of the species to ascertain whether or not it could be reared in ponds. The investigation has been financed by and conducted under contract with the Industrial Research Advisory Council of the Territory of Hawaii (Project No. 29).

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[1] Contribution No. 40, Hawaii Marine Laboratory.

[2] Department of Zoology and Entomology, University of Hawaii. Manuscript received February 11, 1953.

MATERIALS AND METHODS

Twenty-two samples of aholehole, comprising 202 fish with food in their stomachs, were examined (Table 1). Small fish from fresh-water streams (samples 1 to 5), from a brackish-water canal (sample 6), and from tide pools or rocky shores (samples 7 to 14) were caught by seine, dip net, or, in a few cases, hook and line. Medium-size fish (samples 15 and 16) were caught from rocky shores by hook and line. Large fish were caught by poisoning coral reef areas (samples 17 to 20), by spear fishing at a sunken barge (sample 21), and by trap in an inshore channel (sample 22).

For the most part the small and medium-size fish were preserved in formalin immediately after capture. Later the fish were measured, the stomach removed, and the contents examined under a dissecting microscope. The length range of each sample is included in Table 1. Length is defined as the distance from the tip of the closed jaws to the end of the vertebral column (located with a probe). The large fish were measured and dissected as soon as possible after capture. In some cases, the unopened stomachs were placed in vials of formalin; in others the stomachs were opened and the contents were preserved in the vials. The latter procedure seemed more satisfactory, as digestion was halted sooner and the contents were more readily identified because of their better state of preservation.

TABLE 1

AHOLEHOLE SAMPLING DATA, WITH PERCENTAGE BY BULK OF VARIOUS FOOD ITEMS FOUND IN THE STOMACHS

GROUPS, SAMPLE NUMBER, AND LOCALITY		DATE	NUMBER	SIZE (RANGE IN MM.)	ALGAE (AND OTHER PLANTS)	FORAMINIFERA	ANNELIDS	CRUSTACEA	INSECTS	SPIDERS	MOLLUSCS	OTHER
Small Fish from Fresh Water	1 Bellows Field Stream	1/ 6/52	10	20–23	43.0	21.0	...	19.5	4.0	...	...	12.5
	2 Bellows Field Stream	1/ 6/52	10	45–64	73.9	...	...	0.1	16.0	...	...	10.0
	3 Bellows Field Stream	1/26/52	6	54–65	85.0	...	...	1.7	13.3	...	...	...
	4 Kaaawa Stream	2/15/52	10	23–27	68.3	...	...	...	29.7	2.0	...	...
	5 Kaaawa Stream	9/10/52	10	22–39	58.0	...	...	7.5	34.5	...	...	...
				Mean	65.6	4.2	...	5.8	19.5	0.4	...	4.5
Small Fish from Salt Water	6 Ala Wai Canal	3/ 4/52	5	28–35	...	...	...	33.0	4.0	...	63.0	...
	7 Diamond Head	1/22/52	8	22–35	6.2	10.2	...	80.8	0.8	...	0.2	1.8
	8 Diamond Head	4/15/52	10	32–50	+	7.8	...	27.0	46.9	...	18.3	...
	9 Kuhio Beach	6/11/52	10	25–37	15.8	...	...	74.5	9.7	...	...	...
	10 Sandy Beach	1/26/52	8	30–36	...	1.4	...	40.9	56.3	1.3	0.1	...
	11 Kawailoa	2/ 8/52	10	23–30	9.5	...	4.0	53.0	26.0	5.5	2.0	...
	12 Kualoa	5/15/52	10	23–45	...	47.9	...	29.6	22.2	0.1	0.2	...
	13 Lahilahi Point	2/13/52	10	21–37	13.0	0.5	...	70.5	15.5	...	0.5	...
	14 Waimea	2/ 8/52	10	19–40	+	+	0.4	23.4	74.7	1.5	...	...
				Mean	4.9	7.5	0.5	48.1	28.5	0.9	9.4	0.2
Medium and Large Fish from Salt Water	15 Kaena Point	2/12/52	10	59–105	6.0	...	0.5	63.3	17.5	1.0	...	11.7
	16 Makapuu Point	12/23/51	10	73–138	...	...	...	94.0	6.0	...	...	...
	17 Hauula	5/11/52	13	153–201	7.3	...	64.2	26.1	+	...	...	2.2
	18 Hauula	7/ 8/52	14	164–204	0.9	...	+	97.3	0.3	...	0.1	1.5
	19 Hauula	10/ 4/52	5	157–191	...	...	...	98.0	2.0	...	...	...
	20 Diamond Head	6/23/52	8	159–193	0.6	...	0.6	98.7	...	...	...	...
	21 Off Fort DeRussy	3/22/52	5	142–190	...	...	...	90.6	...	+	...	9.4
	22 Pearl Harbor Entrance	2/19/52	10	132–172	...	...	40.7	53.1	0.2	...	+	6.0
				Mean	1.9	...	13.3	77.6	3.3	0.1	+	3.8

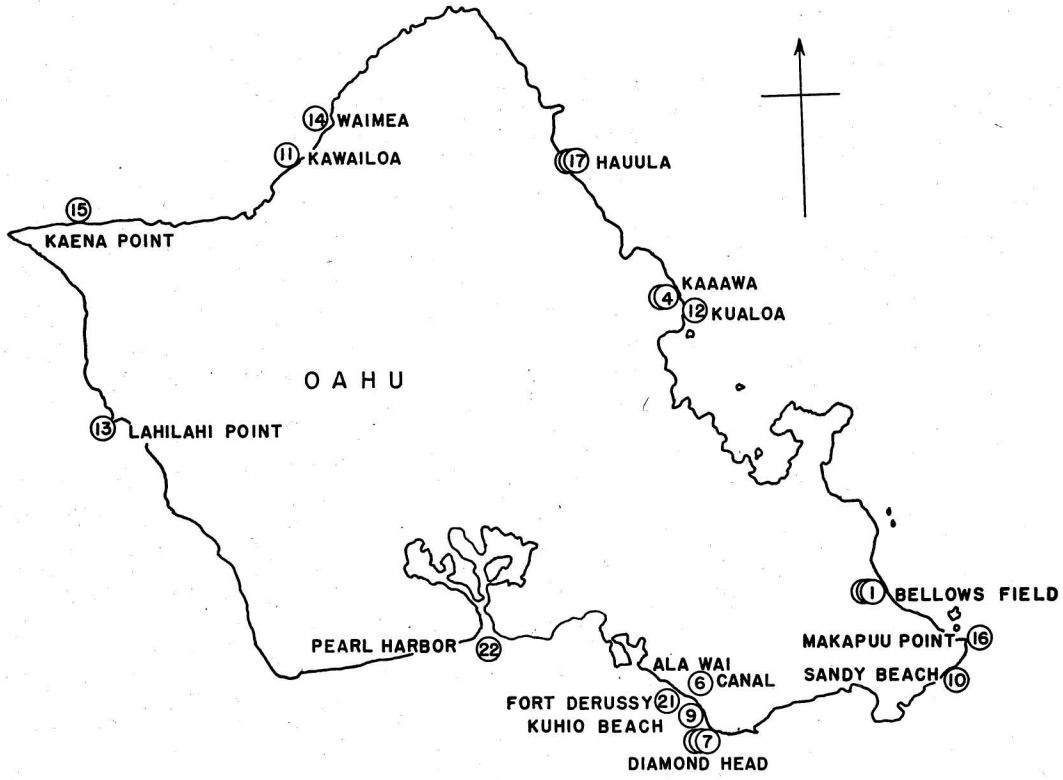

FIG. 1. Map of Oahu showing the location of places from which aholehole samples were obtained.

The items in the stomachs were identified, counted when not too numerous, and expressed as a percentage (estimated) by bulk of the total. In large fish the volume of the contents was also determined, but as this did not vary greatly (*ca.* 2 to 6 ml.) it was not incorporated into the calculations. For each sample a table was prepared showing the frequency of occurrence and the average percentage by bulk of each item. Only the latter figures are included in Table 1.

Organisms were identified usually to order or suborder, often to family, and more rarely to genus and species.

The places of collection, all on Oahu, may be located on the accompanying map (Fig. 1).

RESULTS

It may be seen from Table 1 that aholehole eat seven major types of food: algae, foraminifera, annelids, crustacea, insects, spiders, and molluscs. It is apparent from the grand means that the relative importance of the major groups differs with size-group of fish and with habitat. The results will be discussed according to these two categories.

Small (20–65 mm.) Fish from Fresh Water

Small aholehole from both Bellows Field (samples 1 to 3) and Kaaawa Stream (samples 4 and 5) contained algae, insects, crustaceans, and foraminifera, in order of decreasing percentage. The samples were taken from within the stream mouths in water which was practically fresh (chlorinity 1 to 3 p.p.m.).

Algae and other plant material (averaging 65.6 per cent of the food) occurred in 41 of the 46 stomachs examined. Filamentous red algae (*Compsopogon*) was the most abundant form in samples from both localities. Fila-

mentous green and blue-green algae were also common. Diatoms of various species (*Bacillaria*, etc.) and other one-celled forms such as *Oocystis* were numerically abundant in some stomachs but in bulk constituted a minor item. A few stomachs contained decomposed material, mostly from higher plants, which occurs as a light carpet over the sandy bottom of the stream.

Insects (19.5 per cent) occurred in 19 of the 46 stomachs. They consisted entirely of terrestrial forms—mostly small ants, but also small beetles, springtails, leaf hoppers, and bugs, in order of decreasing percentage. The small ants, of common occurrence in the stomachs, must have fallen into the water by accident. The springtails were probably taken from the surface, where they hop about. Probably the other insects were taken when they accidentally landed on the surface or when they were flying close to it.

The crustaceans (5.8 per cent), occurring in 10 of the 46 stomachs, consisted primarily of fresh-water shrimp larvae, copepods, and amphipods. Foraminifera of several species (4.2 per cent) occurred in four out of six stomachs in one sample only. Similarly small spiders (0.4 per cent) occurred in two out of ten stomachs in one sample. Other food items (4.5 per cent) included unidentified eggs and the remains of a small tadpole (?), each of which occurred in one stomach only.

Small (19–50 mm.) Fish from Salt Water

The small aholehole from Ala Wai Canal (sample 6) have been grouped with those from salt water (samples 7 to 14) as the stomachs contained similar food items, although the chlorinity (13.7 p.p.m.) showed somewhat brackish conditions as compared with those along the seashore (18–19 p.p.m.).

There is considerable variation in the predominating food organism in the various samples. Molluscs were dominant in the sample from Ala Wai Canal; crustacea were dominant in one sample from Diamond Head (No. 7) and in those from Kuhio Beach, Kawailoa, and Lahilahi Point; insects were dominant in the other Diamond Head sample (No. 8) and in those from Sandy Beach and Waimea; foraminifera were dominant in the sample from Kualoa. There seems to be no general relationship between the type of dominating organism and the particular habitat (sandy shore, rocky shore, tide pool). In general, however, crustacea and insects are much more abundant and algae much less abundant in the stomachs of small fish from salt water as compared with those from the fresh-water streams. The difference is interesting but not surprising—it probably reflects a difference in the relative availability of the three types of food rather than a difference in feeding habit.

The food organisms found in the stomachs of small aholehole from salt (and brackish) water may be ranked in the following order of decreasing average abundance: crustacea, insects, molluscs, foraminifera, algae, spiders, and annelids.

Crustacea (48.1 per cent) of one kind or another occurred in 76 of the 81 stomachs. Table 2 shows the various groups arranged according to the average percentage by bulk and shows the number of stomachs in which they occurred.

The copepods, including suborders Cyclopoida, Harpacticoida, and Calanoida, were the most important item of the crustacean diet. They were followed by small amphipods (mostly Gammaridea) and isopods (including Tanaioida). Other crustacean forms occurred infrequently and formed but a small propo-r tion of the food.

Insects (28.5 per cent) occurred in 54 of the 81 stomachs. They occurred in the following decreasing order of abundance: midges, ants, wasps, roaches, beetles, bugs, thrips, and leaf hoppers. Midges and ants, together, comprised the bulk of the insects.

The midges, identified as *Clunio littoralis* by Wirth, occurred in the stomachs as larvae and pupae, but mostly as adults. They were found in all samples taken from tide pools and rocky shores but not in the sample from Ala

TABLE 2
CRUSTACEAN FOOD IN THE STOMACHS OF SMALL AHOLEHOLE FROM SALT WATER, SHOWING FREQUENCY OF OCCURRENCE AND PERCENTAGE BY BULK

CRUSTACEA	NUMBER OF OCCURRENCES	PER CENT OF TOTAL FOOD
Copepods	70	22.3
Amphipods	27	10.0
Isopods	18	4.0
Crab zoea and megalops	15	2.6
Shrimp zoea	3	0.3
Ostracods	11	0.2
Mysids	3	0.1
Barnacle nauplii	1	0.1
Unidentified remains	19	8.5

Wai Canal (with rock walls) nor in that from Kuhio Beach (a sandy shore). They were particularly abundant in the sample from Waimea, occurring in nine of the ten stomachs and comprising 61.0 per cent of the total contents. In a letter to Dr. Hardy, Dr. Wirth states: "Since approximately a fourth of the hundred or so specimens were females, I would not be surprised if the fish were feeding on the midges in the beds of algae where they breed. Since the females are wingless they can only crawl around the breeding places, although some are transported by the males during copulation." This insect, one of the few that breeds in salt water, thus forms an important item in the diet of the small aholehole.

Ants, mostly small adults, occurred often in small aholehole from tide pools and rocky shores. They were particularly abundant in one sample from Diamond Head (No. 8) where they occurred in seven of the ten stomachs and formed 31.5 per cent of the total contents. The ants, which are very common along all shores, doubtless were blown or fell into the water where they were eaten. Some of the winged forms, such as wasps, beetles, etc., may have been taken when they were flying low over the surface or when they accidentally landed on the surface. Although most of the whole insects found in the stomachs were of very small size, a few large legs and wings from unidentified species indicated that the aholehole would also tackle larger forms, nibbling at them until they were consumed.

Molluscs (9.4 per cent) occurred in 22 of the 81 stomachs. They consisted of pelecypod and gastropod veligers and postveligers. There was an unusual abundance of pelecypod veligers in the sample from Ala Wai Canal in which they occurred in all five specimens and formed 63 per cent of the total contents.

Foraminifera (7.5 per cent) occurred in 29 of the 81 stomachs. They were particularly abundant in the Kualoa sample, occurring in nine of the ten stomachs and forming 49.9 per cent of the contents for this one locality.

Algae (4.9 per cent) occurred in 25 of the 81 stomachs. They consisted of the red and green thallus and branched forms common to tide pools and also included diatoms and other one-celled species (of minor importance). The low percentage of algae is in marked contrast to the high percentage which occurred in the stomachs of small aholehole from fresh-water streams.

Annelids (polychaete worms) occurred in only three stomachs. Other items included fish eggs found in two stomachs.

Medium (59–138 mm.) and Large (132–204 mm.) Fish from Salt Water

Medium-size fish (samples 15 and 16) and large-size fish (samples 17 to 22) are grouped as the food was similar and both came from similar habitats—localities exposed to the surf of the open sea where the water is of high chlorinity (19 p.p.m.).

It will be noted from Table 1 that there is less variation in the type of dominant food organism in the samples of this group than in those of the small fish from salt water. Crustacea were most abundant in seven and annelids in one of the eight samples. Compared with the food of the small salt-water fish, there was a marked increase in the per-

centage of crustacea and annelids and a marked decrease in the percentages of all other types of food. No foraminifera were found. The organisms occurred in the following order of decreasing abundance: crustacea, annelids, insects, algae, spiders, and molluscs, with the last two forming very minor items.

Crustacea (77.6 per cent) were by far the most important food of the medium and large aholehole, occurring in every one of the 75 stomachs. The various kinds were distributed as indicated in Table 3.

TABLE 3
CRUSTACEAN FOOD IN THE STOMACHS OF MEDIUM AND LARGE AHOLEHOLE FROM SALT WATER, SHOWING FREQUENCY OF OCCURRENCE AND PERCENTAGE BY BULK

CRUSTACEA	NUMBER OF OCCURRENCES	PER CENT OF TOTAL FOOD
Crab megalops, zoea, and adults	63	49.6
Stomatopod larvae	20	6.9
Amphipods	36	6.3
Shrimp adults and larvae	24	1.8
Copepods	15	1.2
Mysids	10	1.1
Isopods	8	0.8
Euphausids	6	0.1
Ostracods	5	+
Nebaliacians	1	+
Unidentified remains	15	9.8

Crab (Brachyura) megalops were the most important item of the crustacean diet; zoea were common but of minor bulk; small adults were found in only two stomachs. Anomura larvae were found in one sample (No. 21). The remainder of the crustacean food consisted mostly of stomatopods (alima larvae) and amphipods (mostly gammarids, but also hyperiids and caprellids). In contrast to the crustacean diet of the small salt-water fish, copepods were of relatively minor importance to the medium and large salt-water fish. The larger fish tended to eat larger organisms.

Annelids (13.3 per cent) were found in 22 of the 75 stomachs and consisted of unidentified motile polychaete worms. They were mostly of small size (*ca.* 2 cm.), but fragments of larger worms occurred occasionally.

Insects (3.3 per cent) were found in 20 of the 75 stomachs. They were more common in the stomachs of medium-size fish caught at the bases of cliffs than in those of the large-size fish from the outer edges of the reef and the more open water. In the former, the insects consisted of midges (*Clunio*), beetles (Carabidae and Scarabaeidae), and a wasp. In the latter, they consisted of salt-water striders (*Halobates*), a beetle (Staphylinidae), and an ant.

Algae (1.9 per cent) were relatively scarce. Two spiders (0.1 per cent) were found. Molluscs (+ per cent) included a small snail and postveligers. Other items (3.8 per cent) included chaetognaths, sponge gemmules, bottom debris (containing both plant and animal remains), eggs, and fish larvae.

Variation in the Proportion of Stomachs Containing Food

The stomachs of seine and dip-netted small aholehole (19 to 30 mm.) taken from both fresh and salt water almost invariably contained food in either the stomach or gut, although in some cases it was present in traces and was considerably digested. This agrees with the general rule pointed out by Ricker (1946) and substantiated by Orcutt (1950) that, on capture, small fish more frequently contain food in their stomachs than do large fish, a fact which is probably related to their greater activity and faster growth rate. The stomachs of small fish (30 to 50 mm.) taken by hook and line were frequently empty or contained only the bait which was used. Doubtless this method of fishing selected the hungrier individuals.

In the large fish taken by trap (sample 22) the stomachs of all 16 fish contained food. In those taken by spear fishing (sample 21 and others not reported), 12 out of 34, or 35 per cent, contained food. In those taken by poisoning (samples 17 to 20), 100 out of 226, or 44 per cent, contained food. In all these

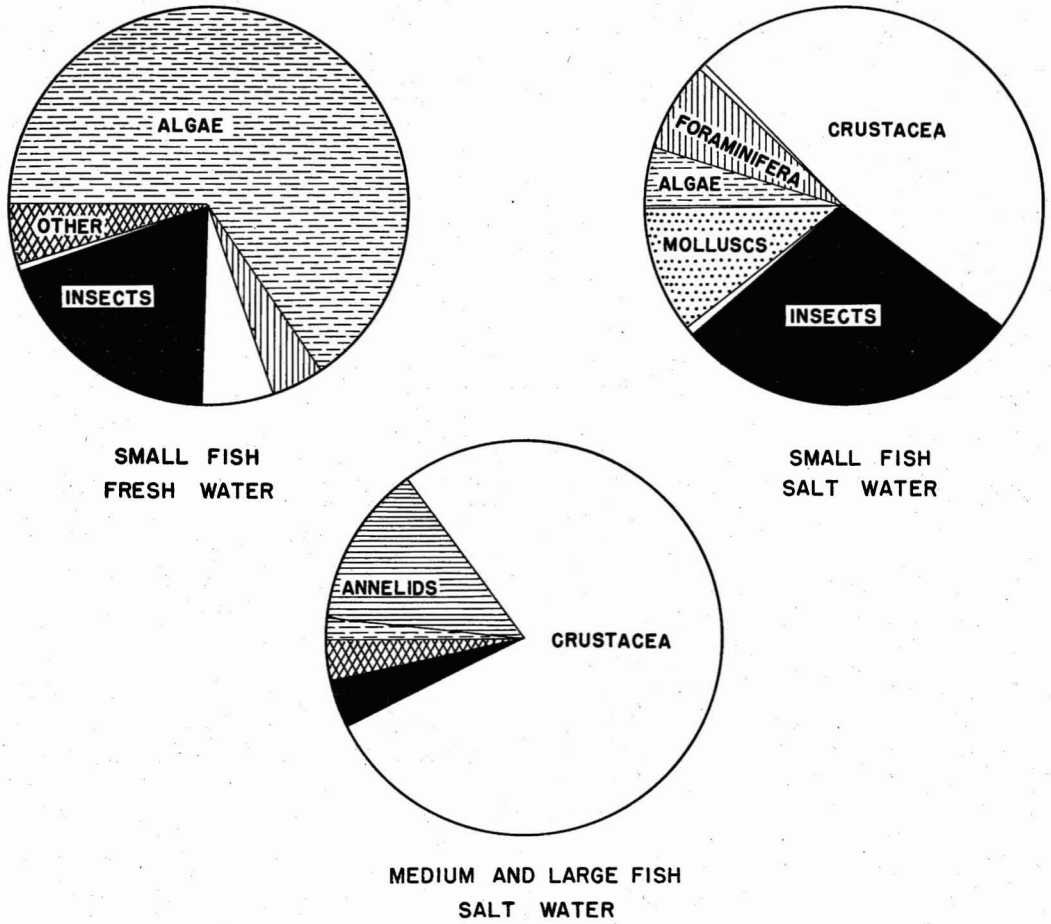

FIG. 2. Diagrams illustrating the food of small aholehole from fresh water, small aholehole from salt water, and medium and large aholehole from salt water.

fish, the gonads were either spent or in early stages of development of the eggs and sperm. In two samples taken by poisoning from Diamond Head (Dec. 22, 1951, and Dec. 23, 1952), the stomachs of all 199 fish were empty except for one which contained sand and gravel. In these fish the gonads were almost fully ripe; in some cases eggs and milt would "run" with pressure on the sides of the fish. This indicates that the aholehole, like several other species, ceases to feed when ready to spawn.

SUMMARY AND DISCUSSION

As illustrated in Table 1 and Figure 2, there are certain differences in the food of small aholehole in fresh water, small aholehole in salt water, and medium and large aholehole in salt water. The small fish living in streams eat mostly algae and insects. The small fish living in tide pools and along rocky shores eat mostly crustacea and insects. The medium and large fish living along surf-pounded cliffs, in the caverns of the outer reef, and in other exposed localities eat mostly crustacea and annelids. Whereas the crustacean diet of the small salt-water fish consists mostly of small copepods and amphipods, that of the medium and large fish consists mostly of the larger crab and stomatopod larvae. These differences, although striking, are not unexpected. They are doubtless related to differences in the

dominant types of food available in the three habitats and to an increasing ability of the fish to take larger organisms as it grows larger and the gape of its mouth increases.

The large percentage of insects found in the stomachs of small fish was unexpected. In the fresh-water samples these were mostly terrestrial forms (ants, beetles, etc.) which had fallen into the water or accidentally landed on the surface. In the salt-water samples they included terrestrial forms (ants, wasps, etc.) but consisted largely of midge (*Clunio*) adults and larvae which breed in salt water along the rocky shores. Insects occurred only rarely in the stomachs of large fish and included midges (*Clunio*) in those taken from the base of cliffs and salt-water striders (*Halobates*) in those taken farther from shore, as well as a few terrestrial species.

The aholehole might be described as omnivorous but with a preference for motile animal forms. Although algae of various species were abundant in the salt-water habitat, they were eaten to only a small extent. The fact that they formed such a large percentage of the food of the small fish in fresh water was probably because motile animal life, of a size suitable to the small fish, was relatively scarce.

Superficially the aholehole resembles the fresh-water Centrarchidae in both appearance and feeding habits. However, in both the smallmouth black bass (Tester, 1932) and the largemouth black bass (Murphy, 1949) there is a change in diet with increase in size to include fish as an important food item. This does not occur in the aholehole, even though larval and juvenile fish of suitable size are present in the habitat. Larval fish were found in only four stomachs and formed a very minor item in the diet of the larger aholehole.

From a study of the natural food, one would infer that crustacea would serve as an ideal bait in angling for the medium and large fish. This is true; we have found shrimp to be the best bait, although the fish will also respond to a hook baited with pellets of bread. Both vegetable material such as bread and poi and animal material such as ground fish and shrimp may be used to chum aholehole to the surface.

As is true of several other species, the aholehole appears to cease feeding when ready to spawn.

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